Competency 1.30 **EH Residents shall demonstrate a familiarity level knowledge of Department of Energy radiation protection requirements sufficient to assess the effectiveness of radioactive material containment, exposure control, and radiological work practices.**

1. SUPPORTING KNOWLEDGE AND/OR SKILLS

a. Discuss the relevant Departmental requirements related to the following radiological control elements:

- Contamination control
- Radiation work permits
- Radiation safety training
- Posting and labeling
- Respiratory protection
- Records
- X-ray generating devices

b. Describe and explain the radiological concerns in the design, construction, and operation of containment and confinement systems.

c. Discuss the design and operational characteristics of containment and confinement systems that minimize personnel radiation exposure.

2. SUMMARY

DOE has the responsibility to establish radiation protection standards that are consistent with guidance developed by several interagency committees under the leadership of the Environmental Protection Agency (EPA). This guidance, approved by the President of the United States, is based on recommendations put forth by four principal scientific committees: the International Commission on Radiological Protection (ICRP), the National Council on Radiation Protection and Measurements (NCRP), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the Committee on the Biological Effects of Ionizing Radiation (BEIR).

DOE issued 10 CFR 835, *Occupational Radiation Protection*, as a means to implement the *Radiation Protection Guidance to the Federal Agencies for Occupational Exposure* (52 FR 2822) and codify existing DOE radiation protection directives. The final rule became effective 30 days after its publication on Dec. 14, 1993 in the *Federal Register*. This regulation establishes requirements for radiation protection of occupational workers at DOE facilities with the intent of ensuring that radiation exposures are kept not only within applicable limits, but as far below these limits as is reasonably achievable. Because DOE recognized that initially meeting the requirements of 10 CFR 835 would be difficult, the final rule required the submission of a radiation protection program (RPP) by Jan. 1, 1995, that would "set forth the plans, schedules, and other measures for achieving compliance" with the requirements of this final rule by Jan. 1, 1996. The RPP is designed to describe those actions that will demonstrate full compliance with 10 CFR 835.

Meeting the requirements set forth in 10 CFR 835 has been aided by the issuance of several implementation guides (IGs). The IGs serve to provide guidance and acceptable methodologies for implementing and conducting a variety of radiation-related programs. Existing implementation guidance exists in the following areas:

- Radiation protection program
- Occupational ALARA program
- Internal dosimetry program
- External dosimetry program
- Evaluation and control of fetal exposure
- Radiation safety training
- Instrument calibration for portable survey instruments
- Workplace air monitoring
- Posting and labeling for radiological control
- Occupational radiation protection recordkeeping and reporting
- Sealed radioactive source accountability and control

10 CFR 835 does not address every essential area needed to form the basis of a comprehensive program to protect individuals from the hazards of ionizing radiation in the workplace. Therefore, DOE issued DOE Notice 441.1, *Radiological Protection for DOE Activities*, to establish radiological protection requirements that, combined with 10 CFR 835 and its associated implementation guidance, form the basis for a comprehensive RPP.

The *Radiological Control Manual* offers detailed guidance for implementation of radiation protection in the DOE system. It establishes practices for the conduct of DOE radiological control activities and states DOE's positions and views on the best courses of action currently available in the area of radiological controls. This manual is intended to be reissued in 1996 as a RadCon Technical Standard. The use of "shall" statements presently in the document will presumably be changed to "should" (or equivalent) statements.
The aforementioned documents serve to satisfy DOE's role in ensuring that all aspects of their management and operating (M&O) contractors' RPPs meet and adhere to those requirements essential for protecting workers, the public, and the environment from all activities conducted under their auspices.

DOE Order 6430.1A, *General Design Requirements*, provides general design criteria for use in the planning, designing, or acquiring of a facility for DOE. When considering the radiological concerns associated with the design, construction, and operation of containment and confinement systems, the Order (p. 13-9) states, "special facilities shall be designed to minimize personnel exposures to external and internal radiological hazards, provide adequate radiation monitoring and alarm systems, and provide adequate space for health physics activities. Primary radiation protection shall be provided by the use of engineered controls (e.g., confinement, ventilation, remote handling, equipment layout, and shielding); secondary radiation protection shall be provided by administrative control. As Low As Reasonably Achievable (ALARA) concepts shall be applied to minimize exposures where cost-effective."

3. SELF-STUDY SCENARIOS/ACTIVITIES AND SOLUTIONS

Scenario 1, Part A

On Aug. 31, two workers employed at a DOE contractor facility were tasked with installing a new process line in an indoor building posted and controlled as a high radiation and high contamination area. This activity was infrequently performed. Both workers had completed Radiological Worker I training and additional training to allow them access into high radiation areas. Both workers were currently in compliance with 10 CFR 835 training requirements. However, one worker (Worker "A") required retraining effective the first day of the following month. The workers had been issued and had signed a Radiation Work Permit (RWP) limiting the scope of work to installing the new line in a shielded area of the building. The RWP required a full set of protective clothing without respiratory protection based on the scope and location of the work. Personnel dosimetry requirements consisted of a pocket ionization chamber (0 to 200 mR scale) and a thermoluminescent dosimeter (TLD) badge.

The workers entered the area and began installing new pipe. Operations continued smoothly until late in the afternoon when the workers discovered an out-of-service drain line interfering with installation of the new line. Unfortunately, they failed to observe a faded "Danger: High Radiation Area" posting placed on the drain line. Because of the time, they decided to quit for the day.

The following morning, the workers informed their supervisor of the situation. The supervisor determined that work could not continue until a flanged pipe tee, connected to the drain line, was removed. Worker "A" attempted to remove the pipe tee, but, having difficulty loosening it, asked for assistance from Worker "B." After five minutes and considerable effort, the tee was successfully removed. Worker "B" observed that one of his gloves had been badly torn during this process, so he removed it and left it on the floor. He then spent a couple of minutes closely examining, touching, and measuring the end of the drain in order to locate a cap that would fit the exposed opening. Not finding an appropriate match, he decided to leave the end open. The two workers spent the following ten minutes one foot away from the old drain line while connecting another section of the new process line. After installation was completed, the workers departed the work area, removed their protective clothing, and performed whole-body frisking. Worker "A" was free of contamination; Worker "B" found contamination on his hands. A radiological control technician (RCT) was notified.

List several areas which require further evaluation in this scenario.

Scenario 1, Part B

Following decontamination of Worker "B's" hand, the RCT performed a survey near the drain line. His instrumentation indicated a whole-body dose equivalent rate of 500 mrem/hr at a distance of 30 centimeters. The RCT observed that the open end of the drain line contained an unknown residue. Taking adequate precautions, he collected samples from the drain line; isotopic analyses performed immediately after collection revealed the presence of plutonium-238 (Pu-238) and plutonium-239 (Pu-239) in the nitrate form. Because of the potential and concern for internal deposition of radioactive material, urine and fecal samples from both workers were obtained for the next several days. Results for Worker "A" were negative. Bioassay results for Worker "B" indicated an intake of 10 Bq of Pu-238 and 12 Bq of Pu-239.

What are some concerns raised in this scenario?

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Activity 1

From the information provided in Scenario 1, Part B, estimate the whole-body external dose equivalent received by workers "A" and "B" due to exposure from the out-of-service drain line only.

NOTE: To aid you in your calculation, assume the workers maintained a constant one-foot distance from the drain line and

- Each worker initially spent five minutes at the drain line discussing what to do about the pipe tee obstruction interfering with their work.
- Each worker spent five minutes attempting to remove the flanged pipe tee.
- Worker "B" spent an additional two minutes examining the exposed drain opening.
- Each worker spent 10 minutes next to the drain line connecting another section of the new process line.

The equation to calculate the external dose equivalent (H) is:

H = dose equivalent rate x time

Activity 2

Review

- DOE Order 6430.1A, *General Design Requirements*.

An architect-engineer has been tasked with designing a building for Facility Z that will have radiological control areas along with several offices. What radiological considerations must the architect-engineer take into account when designing this construction project?

Scenario 1, Part A Solution

The scenario as presented raises several possible areas requiring further evaluation. These include:

- Lack of a prejob briefing.
- Inadequate administrative control. The significance of the change in the scope of the work went unnoticed. The RWP limited work activities to installing only a new drain line.
- Assigning either worker to this task considering the entrance to the building was posted as a high radiation and high contamination area. A higher level of training is typically recommended (see discussion from DOE 10 CFR 835 and the *Radiological Control Manual* below) for entry into these areas.
- Failure of the work supervisor and the workers to adequately investigate and communicate the situation. While the workers notified their supervisor of the drain line obstruction, there was no indication that: (a) the RWP was reviewed to confirm the scope of the work, (b) the supervisor visually inspected the area, (c) the possibility of external radiation exposure or internal contamination from the pipe was discussed, or (d) a radiological control technician was notified to survey the drain line before and after the pipe tee was removed.
- The faded radioactive materials posting that, if observed by the workers, could have alerted them and conceivably led to a minimization of the dose received.
- A lack of contamination control. The pipe tee was removed without the benefit of respiratory protection. Worker "B" also tore a glove and made no attempt to discard the glove in an appropriate manner, perform a contamination survey, and replace the glove.
- Failure to perform radiation surveys in a controlled area, resulting in potentially higher exposures to the workers.
- The lack of health physics surveillance. There is no indication that health physics personnel were present in the building (or that portion of the building) to observe and curtail the operation if warranted.

10 CFR 835 contains several subparts and sections relevant to this scenario.

<u>Subpart E</u> (Monitoring in the Workplace)
Sections 835.402 and 835.404 address individual monitoring and radioactive contamination control and monitoring, respectively. Individual monitoring requirements essentially center around the use of personnel dosimetry.

Subparts F and G (Entry Control Program and Posting and Labeling)

Sections 835.501 and 502 address entries into radiological areas and high/very high radiation areas. Section 835.603 discusses posting requirements for radiological areas. The scenario as presented indicates that posting of the area was performed. Insufficient information exists as to whether all posting requirements and elements of the entry control program were addressed.

Subpart J (Radiation Safety Training)

Section 835.902 is devoted to radiation safety training for radiological workers. This section states requirements for training and retraining at intervals not to exceed two years. In the above scenario, retraining requirements were violated by Worker "A." Even if this individual had the requisite training for entry into these areas, he should not have received authorization to reenter the area on the first day of the month. This section also requires that training be commensurate with each worker's assignment. Since the workers were entering a posted high radiation and high contamination area, a higher level of training is inferred for these conditions

DOE/EH-0256T (Revision 1), *Radiological Control Manual,* contains numerous statements that are applicable to this scenario and the concerns noted on the previous page.

- Articles 122 and 123 address worker attitudes and responsibilities, respectively. The scenario offers some indication that proper respect for radiation and the responsibilities each worker has when dealing with radiation and radioactive materials needs to be reinforced.
- Article 125 discusses the conduct of radiological operations and recommends that a supervisor be "knowledgeable and inquisitive," ask questions regarding the scope of work, and assist in the development of appropriate procedures. In this case, the supervisor should have requested more information from the workers and considered undertaking a visual inspection of the work location.
- Article 126 notes that properly trained workers can perform "supplementary radiological surveys" when a radiological control technician is not present. These workers apparently did not have any radiological instrumentation with them and, as a result, did not perform surveys of any kind.
- Articles 221 and 338 advocate frisking when leaving contamination areas. Worker "B" performed this well enough to detect the presence of contamination on his hands.
- Articles 321 and 322 provide typical information that should be included on, and the rationale for using, an RWP, respectively. Article 324 offers insight into relevant components of a prejob briefing.
- Article 313 discusses the attention and planning that should be promoted for infrequent or

first-time operations. Included in this would be an ALARA review by an appropriate committee and increased line and management oversight. It is conceivable that additional prejob planning might have limited the worker's exposure.

- Article 334 addresses the minimum recommendations for unescorted entry into a high radiation area. Four criteria should be met: completion of Rad Worker II training (with one exception noted in Article 632.5), training in the use of a survey meter, signatures on the RWP, and the use of personnel and supplemental dosimetry. Note that the two workers had completed Rad Worker I and additional training for access into high radiation areas. This additional training satisfies the first condition of Article 334. Both workers had signed the RWP. The workers had presumably been trained in the use of a survey meter, but no survey instruments were carried into the area and no surveys were ever performed. The workers carried personnel dosimetry, but no supplemental dosimetry.

NOTE: Some consideration could conceivably be given to the fact that even though the door to the building was posted as a high-radiation and high-contamination area, the work took place in a part of the building where a radiation area existed. The workers did meet the requirements for work in a radiation area. Even so, Worker "A" should not have been allowed access on the following day.

- Recommendations for unescorted access into high contamination areas include Radiological Worker II training (no exceptions are given), signatures on the RWP, protective clothing and respiratory protection when specified on the RWP, prejob briefings, and personnel dosimetry. Examining these five recommendations, the workers should not have been allowed access to the building because they had not completed Rad Worker II training. As mentioned previously, no pre-job briefing had occurred.
- Articles 631-633 discuss the Radiological Worker Training requirements for access to radiological areas.
- Article 641 advocates that training not only stress normal or routine operations, but also situations where radiological conditions change during the course of performing a particular work function. Dose rates, for example, could increase as the job proceeds, underscoring the importance of recognizing, evaluating, and anticipating changing conditions that could affect a worker's exposure. Training requirements for radiological control technicians and supervisors are specified in Articles 642-644.

Scenario 1, Part B Solution

DOE 10 CFR 835 and the *Radiological Control Manual* address some of the concerns in this part of the scenario.

- The faded radiological posting present on the drain line is a concern. According to 10 CFR 835, Section 601, signs shall be "clear and conspicuously posted." Article 231 of the *Radiological Control Manual* states that postings should "alert personnel to the presence of radiation and radioactive materials," "be conspicuously posted and clearly worded," and "be maintained in a legible condition." The workers' failure to observe the posting is clearly not entirely their fault, but likely resulted in Worker "B" receiving a higher dose.
- The reading of 500 mrem/hr at 30 cm qualifies as a high radiation area under 10 CFR 835 Subpart A, Section 835.2 and as noted in Table 2-3 of the DOE *Radiological Control Manual*. Posting the drain line as a radiation area should have been performed under Article 234.
- 10 CFR 835.402 requires monitoring in the workplace for exposures to internal radiation. Articles 136 and 361 from the *Radiological Control Manual* refer to the difficulty in measuring transuranic uptakes. For that reason, considerable attention should be paid to controlling and preventing internal exposures. Article 316 cites the need for appropriate engineering and administrative controls as primary and secondary methods, respectively, to limit internal exposures. Respiratory protection is the next resort. Because: (1) respiratory protection was not required on the RWP based on the original scope of work (no potential for airborne radioactivity was thought to exist), and (2) the significance in the change in job scope was not recognized by the workers or the work supervisor, respiratory protection was not utilized at the time the pipe obstruction was discovered, removed, and opened. As a result, one of the workers received an internal dose.
- Annual allowable dose limits are provided in Subpart C, Section 202 of 10 CFR 835 and Article 213 of the *Radiological Control Manual*. While the whole body and organ limits were not exceeded in this case, the doses received by the workers were not maintained ALARA.

Activity 1, Solution
(Any reasonable paraphrase of the following is acceptable.)

Calculating the external whole-body dose equivalent received by the workers can only be estimated in this case because there are uncertainties regarding: 1) general exposure rates in the shielded portion of the building where they were working (no information was provided), and 2) the workers' proximity to the drain line at any given time. A constant one-foot distance was chosen to simplify the calculation. Given these uncertainties, the whole-body doses are estimated as follows:

<u>Worker "A"</u>

Worker "A" spent an estimated 20 minutes near the drain line. Therefore, the worker received a dose equivalent of:

(500 mrem/hr) *x* (1 hr/60 minutes) *x* 20 minutes = **167 mrem** or **0.17 rem**

<u>Worker "B"</u>

Worker "B" spent an additional two minutes near the drain line. The dose equivalent is:

(500 mrem/hr) *x* (1 hr/60 minutes) *x* 22 minutes = **183 mrem** or **0.18 rem**

Activity 2, Solution
(Any reasonable paraphrase of the following is acceptable.)

The basic ALARA philosophy can be described as limiting personnel and environmental radiation exposures to the lowest levels commensurate with sound economic and social considerations. However, the ALARA philosophy assumes that no radiation exposure should occur without a positive benefit, considering technological, economic, and societal factors. This statement implies that there is some risk, however small, with any exposure to radiation. One should always look for ways to reduce radiation exposure, as long as the cost of the consideration does not exceed the possible cost of the potential dose savings.

One of the best ways to achieve ALARA is by designing it into a facility from the very beginning. This ALARA engineering (or radiological engineering) ensures that radiation exposures are minimized when the facility goes into operation and that maintenance, repair, or modifications in the facility can be done safely and without significant contamination or radiation hazards.

Each facility will have its own unique set of concerns, so no list can be inclusive, but the following list of considerations for various aspects of building design can serve as a starting point for an ALARA review.

Crud Production and Radioactivity Deposition in Liquid Systems

- Reduce the loss of material from erosion by using good flow geometries and avoiding sharp bends, reducers, and rough internal surfaces.
- Reduce the loss of material from corrosion-resistant materials and by maintaining proper water chemistry.
- Reduce crud deposition by:
  - Providing crud filters, if practical.
  - Ensuring that all equipment is flushable and drainable.
  - Eliminating crevices, elbows, low points, and dead legs.

Airborne Radioactivity and Heating, Ventilation, and Air Conditioning (HVAC)

- Reduce airborne sources and gaseous leakage by:
  - Properly sealing and pressurizing equipment and ducts with such measures as continuously welded seams and flange gaskets.
  - Leak-testing HVAC equipment after installation and repair.
  - Selecting filters appropriate for the radioisotopes used and appropriate to the operation.

- Avoiding filter breakthrough due to overloading by providing pressure sensors or monitors.
- Avoiding open-topped tanks or tanks with vent lines lower than tank overflow lines.
- Using good contamination control practices in designing for and performing such tasks as filter changeout, wet laydown of equipment, machining contaminated parts, etc.

• Use proper air flow:

- To direct air flow from areas of low potential contamination to areas of greater potential contamination, and to exhaust from areas of greatest contamination.
- Within a room, supply air to the cleanest area and exhaust to the most contaminated area.
- To avoid drawing contaminated air across walkways, doorways, entrances, work areas, and especially breathing zones.
- To ensure that the opening of doors, removal of shield plugs, etc., does not disrupt proper air flow.
- To provide local ventilation such as hoods and spray booths where appropriate.
- To be careful about pressurization of clean ducts that pass through contaminated areas, and vice versa, and about reversal of flow in ducts used intermittently.

Decontamination and Contamination Control

• Provide for proper contamination control measures by:

- Selecting packless valves or those using live-loading packing.
- Considering diaphragm or bellows-sealed valve designs.
- Selecting pumps with mechanical rather than packless seals.
- Routing pipe drains, tank overflow, valve stem leakage, etc., to sumps.
- Sloping floors toward sumps or floor drains and using curbs, dikes, berms, and trenches as appropriate.
- Considering whether flooding (due to leakage, backup of a sump, etc.) may cause the contamination of equipment, and elevating such equipment above flood levels.
- Avoiding open gratings for stairs or platforms in potentially contaminated areas. -
- Allowing room for friskers, stepoff pads, and used Contaminated-Zone clothing bins outside contaminated or potentially contaminated areas.
- Planning for eventual decontamination (e.g., if decontamination is done in place, the worker may be exposed to a high dose rate from other equipment in the area, or the worker may not have much room to work in, and the decontamination fluids, cloths, and removed parts will have to be collected. Therefore, the equipment may have to be removed for decontamination.

If the equipment is removed to another location for decontamination, it may have to be bagged up, lifted and loaded, and moved along a path possibly passing through general access areas or areas of narrow clearance).

- Facilitate decontamination by:
  - Providing smooth, nonporous and nonreactive surfaces, whether inside equipment, on floors, on insulation, or for tools. Using appropriate coatings on floors, walls, trenches, doors, plugs, equipment, and even tools.
  - Selecting equipment that can be readily and completely dismantled.
  - Making generous provisions for services for anticipated decontamination: water, air, electricity, and other connections.
  - Considering a central decontamination station for a large facility or operation; size, equip, and locate it for the types, sizes, number, and locations of the equipment it is to handle.
- Equipment decontamination
  - *The Radiological Health Handbook* (1970 edition, pp. 198-203) discusses methods of decontamination. Keep in mind that it is ALARA to select a method that reduces the dose to the worker (including both the direct dose and the airborne contributions), while reducing the volume of radwaste produced.

Radwaste

- Equipment
  - Never undersize a radwaste tank.
  - Select tanks with sloped or dished bottoms containing spargers or sprays.
  - Reduce crud deposition as mentioned earlier. Also use pipes with at least a 1 ½-inch diameter, long bend radii, no right-angle bends, and sloping runs.
- Plugging
  - Avoid long vertical runs ending in a turn to the horizontal, since this leads to plugging.
  - Provide turbulent flow to eliminate homogeneity.

Sampling, Monitoring, and Instrumentation

- Sampling
  - Make sure that the sample is representative of the material sampled with respect to location, physical state, and chemical composition.
  - Provide sample lines that have few and large bends and are flushable.

- Provide a strong and continuous purge of sample lines in high-radioactivity systems.
- Locate sample probes at representative locations. They should normally be upstream and downstream of major filters, at all effluent and air monitor sampling points, and as needed in areas of potentially high airborne activity.
- Locate grab sample taps, particle collectors, and sample filters appropriately. There should be no obstruction of any sample intake.
- Carefully locate sampler intakes for breathing air in an open room, preferably no further than slightly above and in front of the worker's face.

• Monitoring

- Provide sufficient and well-chosen radiation and air monitors to cover all areas where there is a potential for dose rates or airborne concentrations exceeding the limits of the respective areas.
- Make sure that there are no obstructions or blocking of any monitor.
- Process and effluent monitors should be located so as to have enough "detection lead time" to divert or isolate a process stream, if that is their function.
- Provide friskers, portal, and "stand and count" monitors as recommended.
- Make sure that all monitors have circuitry that can detect monitor failure automatically and indicate whether the dose rate is off-scale.
- Provide readouts and alarms that are local, remote, or both, as appropriate. Make sure that the alarms are both visual and audible.

• Instrumentation

- Locate all instrumentation, except for primary sensing elements, in low dose rate areas. Provide calibration from low dose rate areas, if possible.
- Isolate instruments from contaminated fluids whenever possible.
- Follow good practices for crud production to reduce buildup of radioactivity in instruments.

Access Control

• Traffic

- Plan transport routes inside and between buildings so that nonradioactive material does not have to pass through radiological areas, and vice versa. Consider the sizes and locations of monorails, cranes, doorways, corridors, and hatches in order to achieve this.
- Plan personnel traffic routes so that clean or general access areas are not isolated and can be reached without passing through a radiological area.

- Be sure to consider the paths that firefighters will take in entering a radiological area. Try to provide paths that will keep them farthest away from areas of high dose rate while providing adequate access to the area of the fire.

- Radiological Areas
  - Make decontamination and radiation areas as small as possible.
  - Be sure each radiological area is properly posted and is provided with required locks, alarms, interlocks, etc. Use panic bars on the insides of locked doors as appropriate.
  - Minimize the number of access control points. Size them for the expected number of workers that will use them.
  - Provide space for temporary access control points where it is anticipated that they well be needed from time to time.
  - Provide personnel monitors as needed at each access control point.

Shielding, Penetrations, and Routing

- Shielding
  - Obtain information on shielding types and thicknesses from a radiological specialist (e.g., a radiological engineer, ALARA specialist, or health physicist, as appropriate for the project).
  - Consider temporary shielding when shielding would be needed only briefly or infrequently. Allow for space, support, and transport requirements.
  - Consider special shielding, such as shield doors, leaded glass windows, covers for hot spots, transport casks, and shielded carts or forklifts.
- Penetrations
  - Have all affected disciplines review a planned penetration before the hole is made.
  - Minimize the size and number of penetrations; several small penetrations are usually better than one big one.
  - Place penetrations:

1) In the thinnest shield wall, near a corner, as high up as possible, and not in line of sight with a source.
2) So that they do not line up with accessible areas, including stairways, doorways, and elevators.
3) So that they do not line up with any radiation-sensitive equipment attached to a wall or ceiling on the low dose rate side of the penetration.

  - Consider offset penetrations.
  - Seal penetrations where justified, for dose rate reduction, air flow control, and leakage control.
- Routing of Ducts, Pipes, and Cables or Conduit (DPCs)
  - Have DPCs enter through a labyrinth or door, if possible.
  - Do not route DPCs containing contaminated fluids through general access areas, or clean DPCs through potentially contaminated or high dose areas.
  - Locate connections, pull spaces, junction boxes, panels, valve operators, taps, etc., in low dose areas or at least on the low dose rate side of the wall.
  - Provide as short a run of sample and other potentially contaminated lines as possible into the accessible areas.
  - Route clean and radioactivity-containing piping in separate areas, especially pipe tunnels; a worker servicing clean systems should not have to receive a dose.
  - Route so as to provide adequate clearance for maintenance, inspection, and insulation.

Proper Separation, Segregation, and Placement of Equipment

- Separation
  - Put shield walls between components sharing the same cubicle to reduce the dose to a worker maintaining one of them. The equipment should be placed so that the worker does not have to pass close to one to get to the other.
  - Passive equipment, such as tanks, should be separated by shielding from active or frequently maintained equipment.
- Segregation
  - Segregate highly radioactive equipment from moderately radioactive equipment, and both from clean equipment. Similarly, segregate equipment with high airborne potential from equipment with lesser airborne potential, and both from clean equipment.
  - Segregate radioactive equipment of different systems, so as not to have to flush, drain, or decontaminate both systems to reduce the dose when only one needs maintenance.
- Placement
  - Even with shielding, lay out equipment in an area or equipment cubicle so that as a worker enters, he/she progresses from low dose rate to moderate to high dose rate, and from active to passive equipment.
  - Place inspection, control, and readout devices and panels in low dose rate areas.

- Place services (demineralized water, electricity, etc.) near entrances or at least in the lowest dose rate areas.

- Redundancy
  - Provide adequate redundancy and backup capability, especially in systems of high radioactivity content and safety systems.

Accessibility, Laydown, and Storage

- Accessibility
  - Allow adequate working space around major components, usually at least three feet.
  - Size labyrinths and doorways to allow the passage of workers, carts, forklifts, and tools, as appropriate.
  - Consider permanent galleries or scaffolding where maintenance is frequent or prolonged. Provide space and attachments for temporary structures if it is not.
  - Provide space for removal of filters into plastic bags of shielded containers.
- Laydown and storage
  - Provide laydown space in a low dose rate area.
  - Store hot tools (fixed contamination) and tools waiting for decontamination in appropriately posted, locked, shielded, and ventilated areas.
  - Properly store nonradioactive items (e.g., dosimeters, filters, insulation, and so forth that they will not be degraded by radiation, light, moisture, etc.) to be used in radiological areas.

Reliability and Equipment Qualification

- Reliability
  - Select equipment for ease and infrequency of maintenance.
  - Select equipment for length of service life under the expected conditions.
- Equipment qualification
  - Select materials that are qualified for the expected use (i.e., which will not degrade unduly under the expected combined conditions of temperature, humidity, pressure, and especially radiation).

Human Factors

- Visual aids
  - Make sure that signs, indicators, readouts, etc., are clearly legible from a reasonable distance away. Use standard lettering.
  - Provide adequate lighting and consider auxiliary lighting where equipment is located in a corner or behind other equipment, or where remotely operated cameras are used. Provide automatic emergency lighting in areas where the dose rate may be elevated.
- Auditory factors
  - Provide alarms both numerous and loud enough to be heard everywhere in the subject area. Reduce the background noise.
  - Provide adequate communication measures, especially in areas where maintenance and inspection workers or health physics technicians may need to communicate with their supervisors or Health Physics during a job.
- Human physical characteristics
  - Familiarize yourself with an appropriate reference on human sizes and physical capacities. Apply this guidance to all design and operations work.
  - Consider the use of lifting devices and special tools to enable fewer workers to accomplish a job.
- Prevention of human error
  - Make permanent alignment marks on the equipment or floor; color-code tools, conduit, bolts, and piping; place identification on insulation to show what is underneath.
  - Clearly mark system lineup indication of valve position, breaker settings, and the like near controls of equipment.
  - Locate valves, valve operators, controls, etc., logically.
  - Consider automation of operational sequences, or use interlocks and warning lights for dangerous choices in manual sequences. Also, use interlocks as an aid to memory, such as starting a sample hood HVAC when the sample is being drawn.
  - Make it cheap in terms of dose for operations to be accomplished safely. For example, in areas where the "buddy system" is used for safety, provide a low dose rate area where the watcher can observe, perhaps in the labyrinth entrance with a mirror.
  - Use mockups and practice run-throughs.

4. SUGGESTED ADDITIONAL READINGS AND/OR COURSES

Readings

- See DOE Order 6430.1A, Referenced Documents Index, p. 17-35.

Courses

- DOE/EH-4050, *Radiological Assessors Training (for Auditors and Inspectors) Applied Radiological Control* -- Oak Ridge Institute for Science and Education.
- *Applied Health Physics* -- Oak Ridge Institute for Science and Education.
- *Health Physics for the Industrial Hygienist* -- Oak Ridge Institute for Science and Education (REAC/TS).
- *Safe Use of Radionuclides* -- Oak Ridge Institute for Science and Education.